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ON THE VARIATION DUE TO ORTHOGONAL STRAINS IN THE ELASTIC LIMIT IN METALS, AND ON ITS PRACTICAL VALUE AND MORE IMPORTANT APPLICATIONS.

By ROBERT H. THURSTON, A. M. C. E., Member of the Society.

READ APRIL 7TH, 1880.

The writer has, in various earlier papers,* called attention to the important effects of strain in metals in the elevation of the normal elastic

* Increased Resisting Power of Metals under Stress. *Journal Franklin Institute*, 1873; *Iron Age*, 1874; *London Iron*, 1874; *Pract. Mechanic*, 1874; Pamphlet, 8vo., Phila., 1874.

Strength, Elasticity, Ductility and Resilience of Materials of Construction. Trans. Am. Soc. C. E., 1874; *Dingler's Polytechnisches Journal*, 1874; *Journal Franklin Institute*, 1874; Pamphlet, 8vo., Phila., 1874.

Resistance of Materials as affected by Flow, &c. Trans. Am. Soc. C. E., 1876.

Rate of Set of Metals subjected to strain for Considerable Periods of Time. Trans. Am. Soc. C. E., 1876; *Iron Age*, 1877; *Dingler's Journal*, 1877.

limit, and has shown that strain in tension causes in iron a permanent exaltation of that limit, which exaltation may be subsequently taken as a measure of the strain upon which it is consequent; thus overstrain causing accident may be detected by the permanent record so left in the altered character of the metal.*

After a long series of experiments and special investigations, the results of which will be found in papers presented at various dates to the American Society of Civil Engineers, the writer fully determined these facts, and confirmation was found in the researches of Beardslee and others. It was also found by the writer that a definite law governed this exaltation of the elastic limit, relating its amount to the time allowed for set to take place, and to the rate of distortion by unintermitted stress. This law was expressed by a formula† of the form

$$El = a \log. \ t + c.$$

in which, though very variable with differing qualities of metal, for good bridge and cable irons, a=5; c=1.5; El=per cent.; t= time in hours.

The fact was discovered during researches conducted by the writer in the Mechanical Laboratory of the Stevens Institute of Technology, that this same modification of the elastic limit occurs when metals are transversely strained, and this was announced to the American Society of Civil Engineers in a paper‡ presented March 1st, 1876, in which it was shown that in what was called the "iron-class," comprehending both iron and steel, this effect is one of elevation, while, as had been already also shown, on the "tin-class," including the brasses and the bronzes, the effect is to depress the normal elastic limit. Strain-diagrams exhibiting the behavior of the several kinds of metal under these strains, were given as conclusive evidence of the facts presented.

The fact that a permanent distortion of a piece of iron increases its stiffness had been long known. Bell-hangers had, from some unknown but very early date, been in the habit of stiffening wire and guarding

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* On a New Method of Detecting Overstrain in Iron and other Metals, and on its Application in the Investigation of the causes of Accidents to Bridges, &c. Trans. Am. Soc. C. E., 1878; *Sci. American Supplement*, 1878; *Van Nostrand's Mag.*, 1878.

† Ibid.

‡ Note on the Resistance of Materials as affected by Flow and by Rapidity of Distortion. Trans. Am. Soc. C. E., 1876.

against subsequent stretching while in use, by straining it considerably before putting it in place. As early as 1850 Clarke remarked,* "* * * * * if the compressed and extended portions of a wrought iron bar could be, by any artificial means, permanently strained previously to its employment as a beam, such a beam would deflect less than a new bar, and would be practically a stronger beam, since the strength is regulated solely by the bending of the bar."

This idea was also practically applied in 1854 by Werder, at Munich, who stiffened his rods before placing them in the structure, by giving each a permanent extension by tensile stress exceeding the primitive elastic limit. Neither of these, nor the later experiments of Bauschinger (1873) and others, led to the discovery of the elevation of the normal parabolic curve of successive elastic limits, *per saltum*, as finally discovered by the writer, and corroborated by Beardslee, but the increased stiffness noted was attributed to that general, normal, and invariably regular, elevation of the limit by increasing strain, which is seen in all cases and with all materials, and which produces a smooth and usually parabolic strain-diagram.

The writer has now noted and brought to the attention of engineers the fact that the exaltation of the normal elastic limit due to any given degree of distortion in the "iron-class," and its depression in the "tin-class," occurs under intermitted strain, whether the stress be applied longitudinally, transversely, or by torsion, and has presented experimental data proving this phenomenon to thus occur, and experimental quantitative determinations of the law of its variation with time, and the amount of such variation.

He has now to present still another interesting and probably important phenomenon of similar character.

It seemed probable that, if strain in either direction, when exceeding the elastic limit, always produces variation of the normal position of that limit, this effect must be due to a general modification of molecular relations that should modify the effect of the force of cohesion in other directions than that in which the strain had been given. An investigation was made, and this matter was experimentally studied, as opportunity permitted, in the Mechanical Laboratory of the Stevens Institute

* Account of the Brittannia and Conway Bridges, 1850. See "Mechanical Treatment of Metals," by R. H. Thurston, *Metallurgical Review*, 1877, p. 272.

of Technology, until sufficient data was accumulated to give conclusive determinations.

Iron and steel wires broken by tension were found to have the transverse elastic limit abnormally elevated, and to have become very stiff and of comparatively slight ductility. This was true of wires of other metals, and of heavier sections of metal. A large quantity of cold-rolled shafting of all sizes, of which both the longitudinal and the transverse dimensions had been altered by rolling cold, exhibited great increase of stiffness and strength and an even more considerable exaltation of the normal elastic limit. Torsion similarly stiffened wires and rods longitudinally, and test pieces longitudinally strained, become stiffer against torsionally and transversely applied stress. Thus, orthogonal strains mutually affect orthogonal resistances of metals; and the engineer is, by this fact, compelled to study these mutual influences in designing structures in which the stresses approach or exceed, separately or in combination, the normal *primitive* elastic limit of his material.

The following is, in detail, an account of the behavior of a bar of "good merchant iron" under the action of intermittent and successively applied orthogonal strain (transverse succeeded by tension):

A bar of good bridge or cable iron 2 inches square and about 4 feet long was split longitudinally; one-half was cut into tension test pieces, and the other half bent on the transverse testing machine to an angle at the middle of about 120 degrees; the bent bar was then cut into tension test pieces like the first, and finally all these pieces were broken in tension.

On examining the results thus obtained it was found that the original elastic limit of the metal, as exhibited by the test of the unbent bar, had been exalted by transverse strain in all parts of the bar which had been so strained before being tested by tension. This elevation of the primitive normal limit had not occurred, as would have been expected, to the greatest extent at the points most strained,—*i. e.*, nearest the bend at the middle of the strained bar—and less and less as the point of maximum strain was departed from, until, at the ends of the bar, this elevation became much less observable; but it took place irregularly, and, on the average, about as much at one part as at another.

The following are the figures obtained (the bent bar was cut into eight and the unbent into six pieces, and numbered consecutively from end to end):

I.—Effect of Transverse Strain on the Tensile Elastic Limit.

(Elastic limit in pounds per square inch, and kilograms per square millimetre.)

Unbent Bar.			Bar Strained by Bending.		
	Kg. per Sq. m.m.	Lbs. per Sq. In.		Kg. per Sq. m.m.	Lbs. per Sq. In.
No. 1	16.3	23 300	No. 1[1]	21.6	30 900
" 2	16.7	23 800	" 2[1]	23.5	33 500
" 3	16.9	24 100	" 3[1]	18.2	26 000
" 4	16.4	23 400	" 4[1]	19.6	28 000
" 5	14.6	20 800	" 5[1]	22.4	32 000
" 6	15.7	22 400	" 6[1]	19.6	28 000
			" 7[1]	22.4	32 000
			" 8[1]	19.8	28 200
Average	16.1	22 967	Average	20.9	29 825

The elevation of the primitive elastic limit, in this instance, is thus seen to have been 30 per cent., as an average, and in some parts of the bar about 50 per cent. The new series of the elastic limits are seen to be less uniform in value than in the original bar; but, comparing adjacent pieces, in no case is the elevation of the limit less than 1 ton on the square inch, and it usually amounts to more than double that figure. Singularly, also, the greatest change has been produced farthest from the middle, and the least at that point (Nos. 1 and 6, at the ends of the unbent bar, correspond to 1 and 8 of the other; and 3 and 4 of the first and 4 and 5 of the latter correspond, both pairs being from the middle).

It should be observed that the quality of the bar tested, although good as metal of that size runs in the market, is not high, and is not as regular as it should be. It is a "50,000 pound iron."

But the transverse strain here produced, and which is seen to have so greatly modified the primitive elastic limit of the metal, had not materially or even observably affected its ultimate tenacity; this is seen by a comparison of the results of tests *to* the point of fracture, thus:

II.—Effect of Transverse Strain on Ultimate Tenacity.

(Tenacity in pounds per square inch, and kilograms per square millimetre.)

Unbent Bar.			Bar Strained by Bending.		
	Kg. per Sq. m.m.	Lbs. per Sq. In.		Kg. per Sq. m.m.	Lbs. per Sq. In.
No. 1..........	40.9	58 450	No. 1^1......	34.1	48 700
" 2..........	34.5	49 330	" 2^1.......	34.7	49 500
" 3..........	35.4	50 520	" 3^1........	33.5	47 900
" 4..........	35.6	50 980	" 4^1.......	37.5	53 600
" 5..........	36.8	52 540	" 5^1........	36.4	52 000
" 6..........	30.1	42 980	" 6^1........	36.8	52 600
			" 7^1........	36.2	51 700
			" 8^1........	33 4	47 700
Average......	35.6	50 800	Average.....	35.3	50 475

It is seen that the two averages are as nearly identical in value as could be expected, and that the average ultimate resistance to rupture was apparently not altered by the straining due to transverse stress.

Yet, noting the difference of the figures for adjacent parts of the two stripes into which the original bar was split, we may make an interesting comparison, thus:

III.—Effect of Transverse Strain in Elevating the Primitive Elastic Limit and Ultimate Tenacity.

(Differences by comparing Tables I and II.)

	Elevation of Elastic Limit.		Increase of Ultimate Tenacity.	
	Kg. per sq.m.m.	Lbs. per sq. In.	Kg. per sq.m.m.	Lbs. per sq. In.
No. 1^1 No. 1........	5.3	+ 7 600	6.8	— 9 700
" 2^1 " 1.........	4.1	+ 10 200	6.3	— 8 950
" 3^1 " 2	1.6	+ 2 200	1.0	— 1 430
" 4^1 " 3.........	2.2	+ 3 900	2.2	+ 3 080
" 5^1 " 4	6.0	+ 8 600	0.7	+ 1 020
" 6^1 " 5.........	5.0	+ 7 200	0.1	+ 160
" 7^1 " 6.........	6.7	+ 9 600	6.1	+ 8 720
" 8^1 " 6........	4.1	+ 5 800	3.3	+ 4 720

(We compare No. 3 with No. 4^1 and No. 4 with 5^1, because the middle of the bar falls, in the one case, between 3 and 4, and in the other, between 4^1 and 5^1.)

On examination of these figures we are struck by their irregularity, by the fact that the greatest changes both of elastic limit and of tenacity are produced at the ends of the bar, and by the singular phenomenon of an apparent *decrease* of tenacity at one of the ends of the bar. It seems improbable, however, that the latter effect can have been consequent upon any deformation of the bar; it may be more probably attributable to local defect in that end of the strained strip, due to cinder streaks. From the irregularity noted it seems evident that good iron, so called, may possess—as indeed inspection usually indicates—great local defects.

Again, Bars of iron were subjected to severe lateral compression, increasing their length and decreasing their cross section about 15 per cent.; then testing the metal by longitudinal strain, *i.e.*, by orthogonal stress, the writer obtained the following average figures :

TESTS BY TENSION AFTER LATERAL COMPRESSION.

	Elastic Limit.		Tenacity per Unit of Area. Original Section.		Tenacity per Unit of Area. Fractured Area.		Extension.	Modulus of Elasticity.
	Lbs. on Sq. Inch.	Kg. per Sq. m.m	Lbs. per Sq. In.	Kg. per Sq. m.m	Lbs. per Sq. In.	Kg. per Sq. m.m	Per Cent.	Lbs. on Sq. In.
Unstrained Bar	30 000	21	52 500	36.5	89 870	64	24.6	25 270 750
Strained Bar...	59 000	42	69 000	49.	105 600	75	10.4	26 230 500

Thus it is seen that lateral compression to this moderate extent may elevate the longitudinal elastic limit nearly 100 per cent., may increase the longitudinal tenacity 33 per cent. and may raise the modulus of elasticity 4 per cent., while decreasing the ductility in the orthogonal direction 60 per cent.

A similar experimental determination of the effect of equal lateral compression on resistance to flexure gave the following figures:

FLEXURE AFTER LATERAL COMPRESSION.

Cylindrical Bars 1⅛ in. diam. x 40 inches between supports (2.8 c. m. x 1 m.)

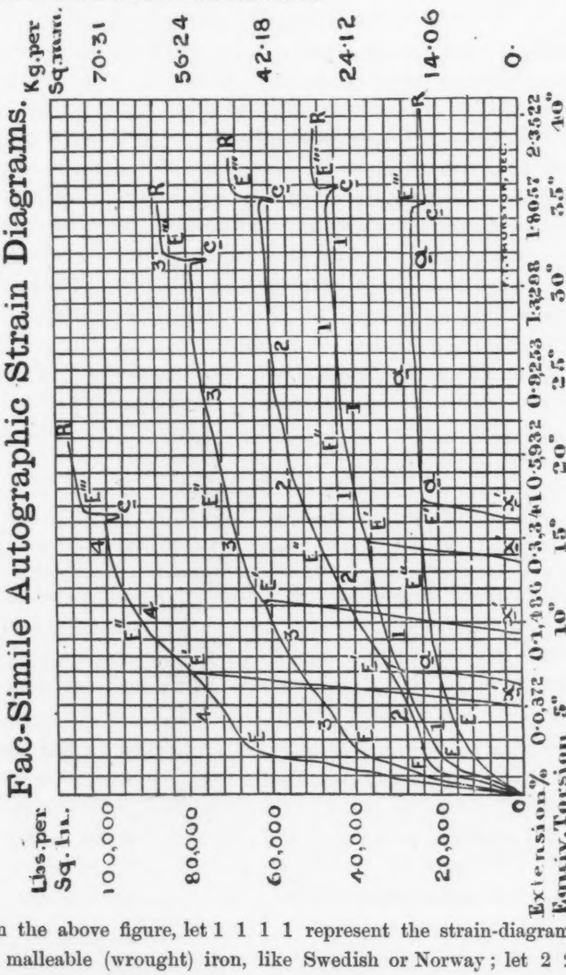
	Load at Elastic Limit.		Modulus Elasticity.	Max. Load.		Resilience at Max. Deflection.	
	Lbs.	Kilog.	Lbs. per Sq. In.	Lbs.	Kilog.	Ft. Lbs.	Kg. m.
Unstrained Bar..	1217	553	27 174 500	1870	850	552	76.5
Strained Bar.....	2700	1227	25 691 500	3395	1543	1049	145.

Thus lateral compression to the extent here practiced increased the elastic limit in flexure more than 100 per cent., *reduces* the modulus of elasticity as estimated from flexure 6 per cent., increases the maximum resistance 90 per cent., and nearly doubles the resilience at maximum deflection (4 in.= 0.1^{m}).

From the fact that the changes produced by cross-bending are felt in internal strain occurring, not simply near the point of flexure, but throughout the whole extent of the beam flexed, it would seem that shearing strains are more serious and general than we have hitherto supposed. This latter is a matter of importance in determining a correct theory of transverse strain, and the subject is undoubtedly deserving of extended aud careful investigation with a view to discovering precisely the nature and intensity of such strains under all usual conditions in all

the materials of engineering construction—first feeling out these strains in the manner here indicated, and then working up the details of the theory until a complete and satisfactory analysis is attained.

CONCLUSIONS :—We may now summarize the results of the study of this subject, so far as the writer has yet presented them, and the conclusions to which he has been conducted.



In the above figure, let 1 1 1 1 represent the strain-diagram of a soft, malleable (wrought) iron, like Swedish or Norway; let 2 2 2 2

be that of a good common merchant iron of small size ; let 3, 3, 3, 3, be the diagram of a mild, and 4 4 4 4 that of a tool steel ; while, in contrast to these examples of the "iron-class," let *a, a, a, a,* be the strain-diagram of a metal of the "tin-class ;" for example, a ductile brass or bronze.

When these metals are strained, they are always found to exhibit a gradually increasing resistance pretty nearly proportional to the extent of change of shape, until a point, E, is reached, when the rate of increase of extension becomes greater—usually very much greater—and the deformation remains permanent when the piece is unloaded, and very nearly equal to the distortion under the load. The removal of the load then, if it is not renewed, gives a strain-diagram O, E, E^1, x^1, the distortion being permanent at x^1. This is the natural or "normal" curve, and it exhibits the normal and long known form of elevation of elastic limit. At the last moment, when the load and distortion are measured by the ordinate and the abscissa, respectively, of the point E^1, the elastic limit has become a maximum. Had the piece strained broken at E^1 the limit of its elasticity would have become identical with the limit of strength and point of rupture, and its measure would have become identical with the modulus of rupture ; for, considering the piece as unbroken at this point, the distorted piece would have for its strain-diagram the straight line E^1, x^1, and would have now been broken when loaded, at the moment that the stress attained the magnitude measured by the vertical let fall from E^1 to the base line. The point E on each diagram marks what is usually known as the Elastic Limit. To distinguish this from the successive limits of elasticity which are due to permanent successively increasing strains, the writer has called the natural and original apparent limit of elasticity, E, the "*Primitive Elastic Limit*," and any other points, E^1, E^{11}, in a smooth curve representing a strain-diagram exhibiting the effect produced by unintermitted and regular distortion, the "*Normal Elastic Limit*" of the piece when in such condition of deformation, the whole curve being, as has been stated, a "*Curve of the Loci of successive Elastic Limits.*"*

This normal elevation of the elastic limit, therefore, as strain progresses and permanent deformation increases, occurs regularly, and the

* On the Mechanical Treatment of Metals, and on the Elevation of the Elastic Limit. R. H. Thurston.—*Metallurgical Review*, 1877.

Ueber die Natur der Elasticitälsgrenze und die Art Ihrer Veranderungen. R. H Thurston. —*Dingler's Polytechniches Journal*, 1877.

strain-diagram takes the form of a smooth curve such as has been long known to represent it, and such as will be found in Morin's "Resistance des Matériaux" and other works published during the last quarter century.

But, instead of producing a regularly increasing deformation by regularly increasing stress, let load be steadily added until at some point E^{111}, corresponding to a distortion O, E^{111}, further addition of load ceases, and the piece remains permanently distorted. The metal now gradually yields, and there occurs a depression, c, of the elastic limit, which in the iron-class soon reaches a limit, but in the tin-class, if the load be not wholly or partly removed, may continue until rupture or maximum possible deformation takes place. Now, renewing the stress, it is invariably observed that this depression of elasticity is, in the case of the iron-class, only apparent; for the extension of the strain-diagram now takes place at a higher range, $E^{111}\ R$, and we observe at E^{111} that phenomenon of "Exaltation of the Normal Elastic Limits" which has been studied by the writer, as seen at E^{111} in curves 1, 2, 3 and 4, and which has until recently been unnoticed by authorities.

Making the same experiment on metals of the tin-class, we usually observe the depression of the normal succession of elastic limits which distinguishes this class from the first, as at E^{111} in $a\ a\ a\ a$; sometimes, however, this depression is unobservable.

This distinction between the two kinds of metals has been shown to have peculiar importance in its bearing upon the permissible values of the factor of safety in structures of metal, the value allowable in constructing in iron or steel being lower, and that demanded in parts composed of the second class of metals being higher than would be proper except for this singular characteristic.

Studying the effect of rapidity of distortion, we find that in the case of the iron-class greater rapidity of distortion causes a decreased resistance, and that a slowly produced deformation causes relatively higher resistance, while the opposite is the case with metals of the second-class.* We see that the rate of set is also related to the time allowed for it.† It thus happens that with the same metals strained at such a rate as to give a strain-diagram 1 1 1 1, an accelerated distortion may produce the

* On the Resistance of Materials as affected by Flow and by Rapidity of Distortion. Trans. 1876-7.

† On the Rate of Set of Metals. Ibid.

diagram 2 2 2 2 or the diagram *a a a a*, accordingly as the metal is of the first or the second class.

Still further, it has been shown in the earlier part of this paper that the exaltation of the elastic limit in iron, &c., is not confined to the direction of the strain produced, but that it affects the metal in such manner as to give it an exalted elastic limit with respect to all subsequent strains however applied. Thus, the engineer may make use of any method of strain that he desires or that he may find convenient, to secure the condition of increased stiffness that he may desire in any given direction. He may strain his bars in tension to secure stiffness in either tension, compression or transversely, or he may give his bars a transverse set to obtain a higher elasticity in all orthogonal directions, or he may compress the metal, as by cold-rolling, and thus secure enhanced stiffness and elasticity in either longitudinal or transverse directions.*

Finally, the writer having shown that the exalted elastic limit being a permanent and determinable effect of any strain which exceeds the "primitive elastic limit," it must remain a permanent and ineffaceable record of the maximum load borne by the metal; this fact is seen to be of inestimable importance, as it enables the engineer to trace such distribution of strain as may have occurred in a wrecked structure,† to determine the location of defective and flawed pieces, and to ascertain the distribution of strains generally, whether in structures or in single members.

This last suggestion may, perhaps, prove of more value to the profession than that relating to the increased safety due to this exaltation of the normal limit of elasticity. The value of this method of investigating experimentally the distribution of stress with a view to determining a correct theory of resistance of materials and of stress, is also probably obvious to every student of the imperfect and largely hypothetical mathematical method of treatment of the subject now usual.

These practical, readily applicable and exceptionably important facts seen to be derivable from a careful and intelligent study of the position and of the method and extent of Variation of the Elastic Limit in metal, whether in single masses exposed to strain, or in structures, lend full

* See report by the writer, "On the Strength, Elasticity, Ductility and Resilience of Cold-rolled Iron and Steel." Pamphlet, 8vo, Pittsburgh, 1878.

† On a New Method of Detecting Overstrain, &c., and its Application in the Investigation of Causes of Accident to Bridges and other Structures; Trans. Am. Soc. C. E., March, 1878.

confirmation to the remarks of the writer before the American Society of Civil Engineers, when first presenting this need of studying the elastic limit more carefully even than the ultimate resistance of metal:*

"In determining the value of materials of construction, it is usually more necessary to ascertain the position of the limit of elasticity and the behavior of the metal within that limit, than to determine ultimate strength, or except, perhaps, for machinery, even the resilience. The fact is becoming recognized that it should be possible to test every piece of material which goes into an important structure, and *to then use it* with confidence that it has been proven to be capable of carrying its load with a sufficient and known margin of safety. * * * The method here described" (by use of the Autographic Testing Machine) "allows of this practice with perfect safety. The limit of elasticity occurs within the first two or three degrees, and as seen, the standard specimen may be twisted a hundred or even sometimes two hundred times as far without even reaching its maximum resistance, and often far more than this before actual fracture commences. It is perfectly safe, therefore, to test, for example, a bridge rod up to its elastic limit, and then to place it in the structure with a certainty that its capacity for bearing strain without injury has been determined, and that formerly existing internal strain has been relieved. The autographic record of the test would be filed away and could at any time be produced in court as evidence—like the 'indicator diagram' of a steam engine—should any question arise as to the liability of the builder for any accident, or as to the good faith displayed in fulfilling the terms of his contract."

We now see that beyond all this lies open to the Engineer a wide and important field of study, and that in the knowledge attainable by an investigation of the characteristics of the metal used in construction, as revealed to him by its behavior far within the limit of final or even incipient rupture, and as pictured in the strain diagram, he may find precisely that knowledge which is most essential to him where either economy or safety is of primary importance.

The subject is only just beginning to secure the attention that its importance demands, but it is to be hoped and fully anticipated that we may soon learn much more in relation to it, and that Engineers will ere long make daily application of facts now discovered and of methods already made familiar to them.

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* Strength, &c., of Materials of Machine Construction; Trans. Am. Soc. C. E., 1874; Reprinted, 8vo, N. Y., 1874.

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TRANSACTIONS.

NOTE—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CXCII.

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EXPERIMENTS WITH APPLIANCES FOR TESTING CEMENT

By ALFRED NOBLE, C. E., Member A. S. C. E.,

WITH A DISCUSSION ON THE SUBJECT,

By D. J. WHITTEMORE, C. E., Member A. S. C. E.

PRESENTED AT THE ELEVENTH ANNUAL CONVENTION OF THE SOCIETY.

The testing of cements has, during the last few years, engaged the attention of many engineers, who have put the results on record. The discrepancies in the results obtained by the same experimenter at different times, and those in the results obtained by different experimenters at the same time, are remarkable. Some of the sources of these discrepancies have been investigated and explained.

Two important causes of discrepancies between the results obtained by different experimenters, are the differences in thoroughness of manipulation, and the difference in the form of moulds and clutches or clips, the first of these causes cannot be removed entirely while the mixing is done by hand, but if some form of mould and clip were generally adopted as a standard, it is probable that with a common method of mixing, more uniform results would be obtained, and the tests made by different experimenters would become comparable. My experience leads me to the conclusion that the selection of the mould and clip will be a difficult matter. This paper will be confined in the main to an account of some experiments in this directton, their object being the selection of a form of mould and clip which would give uniform results and develop the full strength of the cement.

In the construction of a new ship-lock at the St. Mary's Falls Canal, all face-stones were set in mortar of Portland cement. General Weitzel, of the U. S. corps of Engineers, the engineer in charge, required that all this cement should be tested, leaving the details of the work to the writer.

The form of mould adopted is shown on Plate No. II, as Mould No. 1. It resembles the form first used by Mr. Mann, and more nearly the form used by General Gillmore in 1877. The cement and water were carefully weighed, and mixed with a hoe in the box shown on the plate, the blade of the hoe being reduced in width to $\frac{1}{8}$ inch less than the bottom width of the box. All the water required was added at once. The temperature of the water used for mixing was below 40° ; that of the room in which the briquettes were moulded and of the water in which they were immersed was between 60° and 70°. I have no doubt that the mortar can be mixed and ground together much more thoroughly, and in much less time in this way than with a trowel. The mixing, when properly done, is very hard work. With the proportions of 35 of cement to 7 of water, a strong, active man can mix the materials to a plastic mortar in 1½ minutes, though in constant work a somewhat longer time is required. About $\frac{1}{6}$ of the mortar required to fill the mould is put in at a time and carefully tamped, with a light stick shod with zinc to prevent the adhesion of the mortar ; the mortar is finally heaped on the mould, and a pressure applied with a piece of board held in the hands : to prevent the adhesion of mortar to the board the mortar is covered with a slip of paper before applying the pressure. After the

mortar has set the briquette is levelled off to the mould with a broad chisel. Mortar for one briquette only is mixed at one time. The breaking section of the briquette is 1½ inches square.

In my earlier experiments a form of clip was used with which the metal came in direct contact with the briquette at the shoulders; the result was in most cases a break between the points of contact, of one of the clips, as noted by Mr. Mann, although the clips were in such a form that they had no tendency to collapse, which he adduces as the probable cause of this irregular break; whatever may be the cause, the fact remains that in some way, through the contact of the clip, the briquette was so injured at that place as to become weaker than at the smallest cross-section.

The heads of our briquettes were too small to permit drilling holes through them as recommended by Mr. Mann, and, as I wished to make use of the moulds already on hand, I devised (in 1877) the clutch shown on the plate as clutch No. 2. In using this clutch the head of the briquette was seized between the parallel plates of the clutch which were set up against it by set screws. Slips of pure sheet rubber, about ⅛ inch in thickness, were interposed between the plates and the briquette to increase the friction and equalize the pressure. This clutch was too heavy to use in breaking briquettes of American cement a week old, because many briquettes would break in handling with the heavy clutches attached; so the lighter clutch shown on the plate as No. 1, involving the same principle of holding by friction, was devised by Mr. McNaughton, who had charge of the testing room; finally, this last form, with a heavier clamp bar, has been used recently for all kinds of cements.

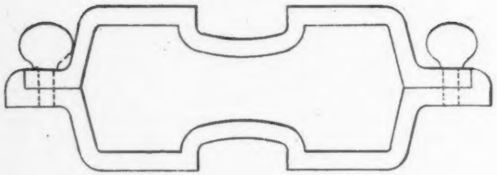
The average results obtained by this apparatus were remarkably high; the average strength of briquettes of pure Portland cement at the age of seven days was over 500 lbs. per square inch; at one time during the last summer, with a particularly good lot of Portland cement, several hundred tests gave a mean of over 600 lbs. per square inch; a large number of briquettes broke at that age under strains exceeding 650 lbs. per square inch, and a few at strains exceeding 800 lbs. per square inch.

The defects of these clamps found by use are as follows: if too great a pressure be applied to the head of the briquette it will be crushed and the test lost; this occurs frequently with mortars of low tensile and crushing strength, and it requires careful management to apply enough

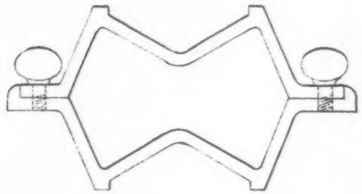
MOULDS, CLUTC

FOR TESTI

Mould No.1.



Mould No.2.

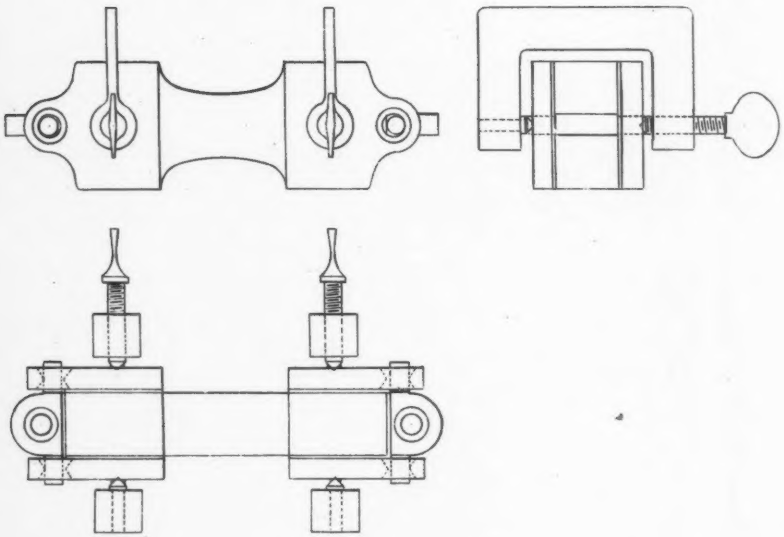


S

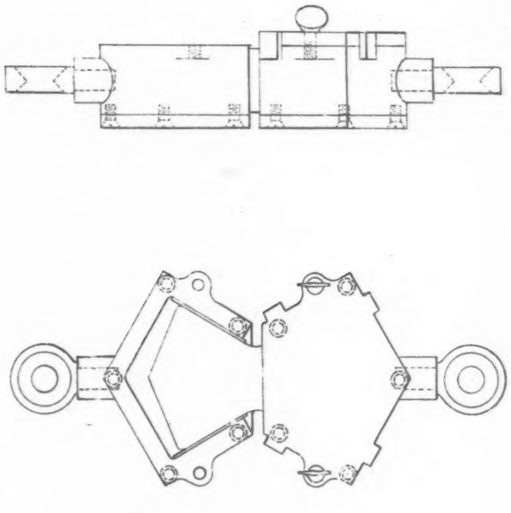
for mould

for mix

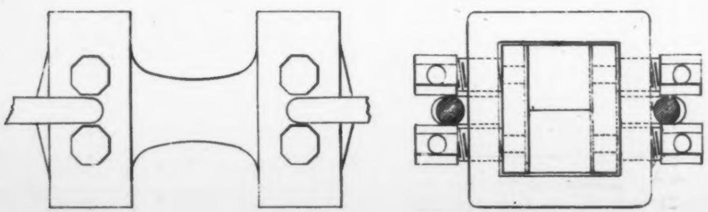
M



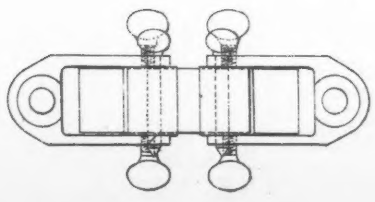
Clutch No.1.



Clutch No. 3.



Clutch



Clutc

MOULDS, CLUTCHES AND MIXING BOX FOR TESTING CEMENT.

PLATE II.
TRANS. AM. SOC. CIV. ENG'R'S
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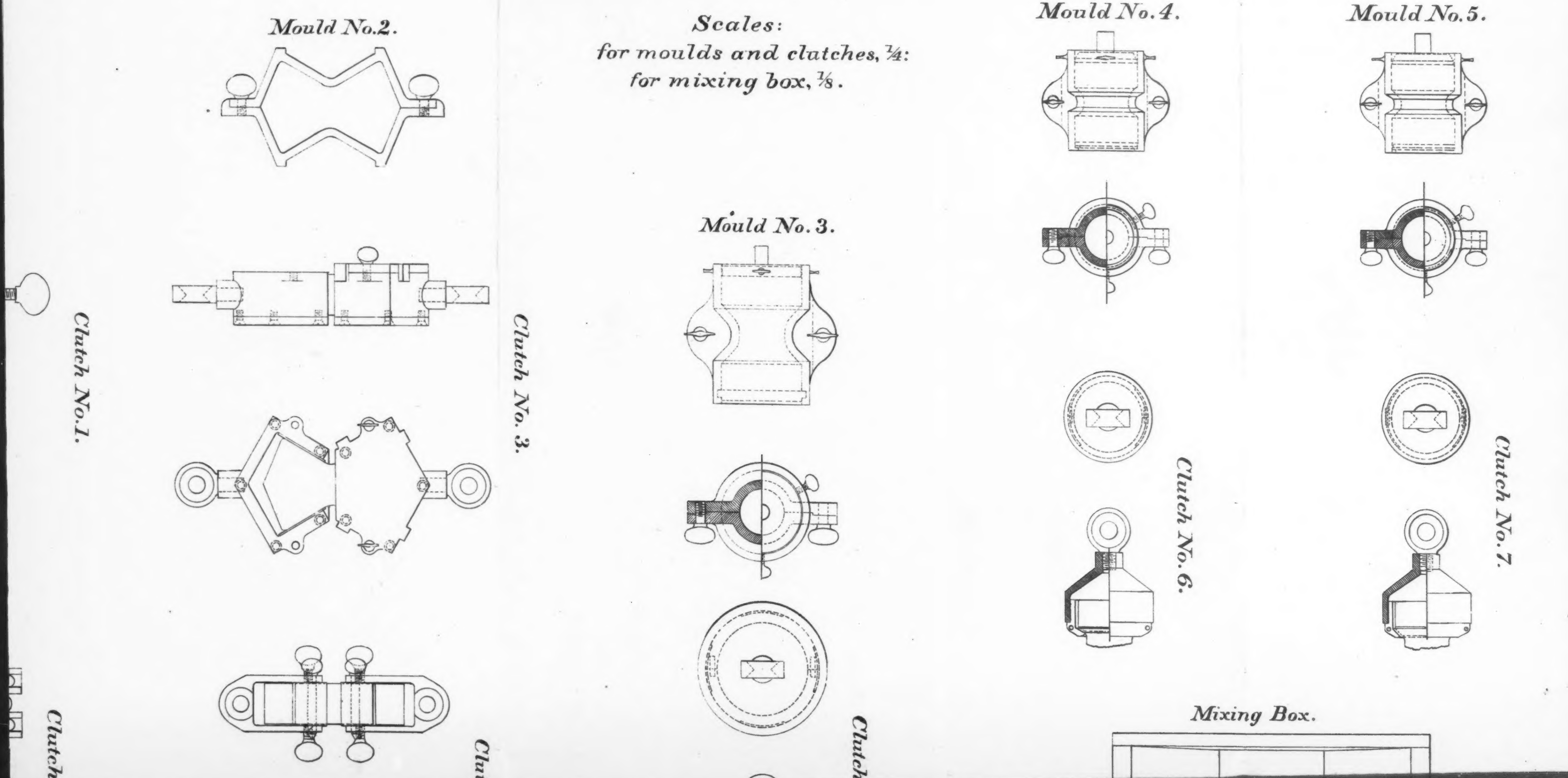
NOBLE ON APPLIANCES
FOR TESTING CEMENT.

Scales:
for moulds and clutches, ¼:
for mixing box, ⅛.



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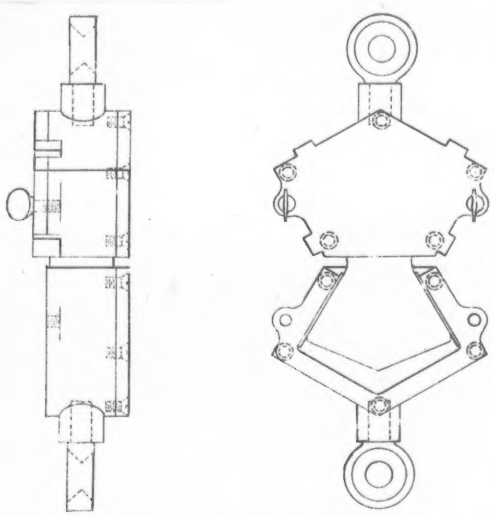
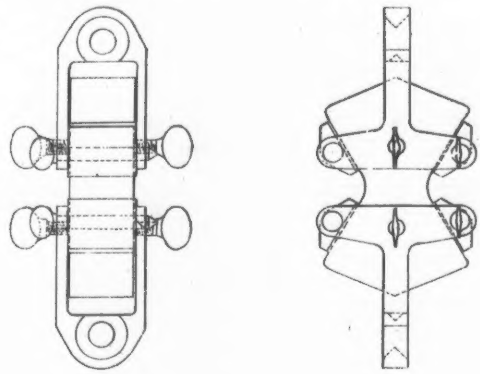
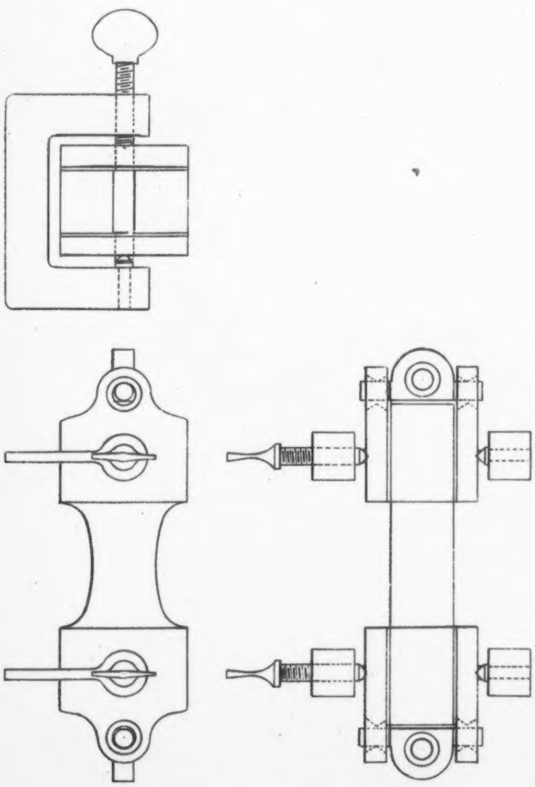


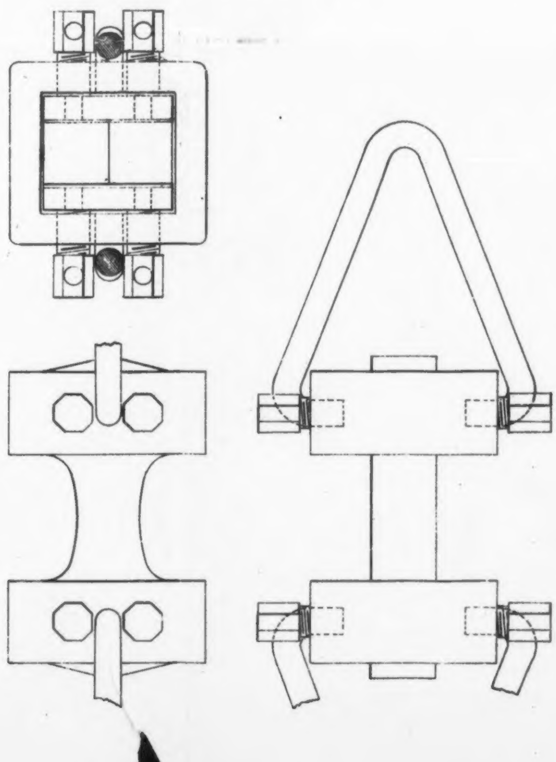
Clutch No. 4.

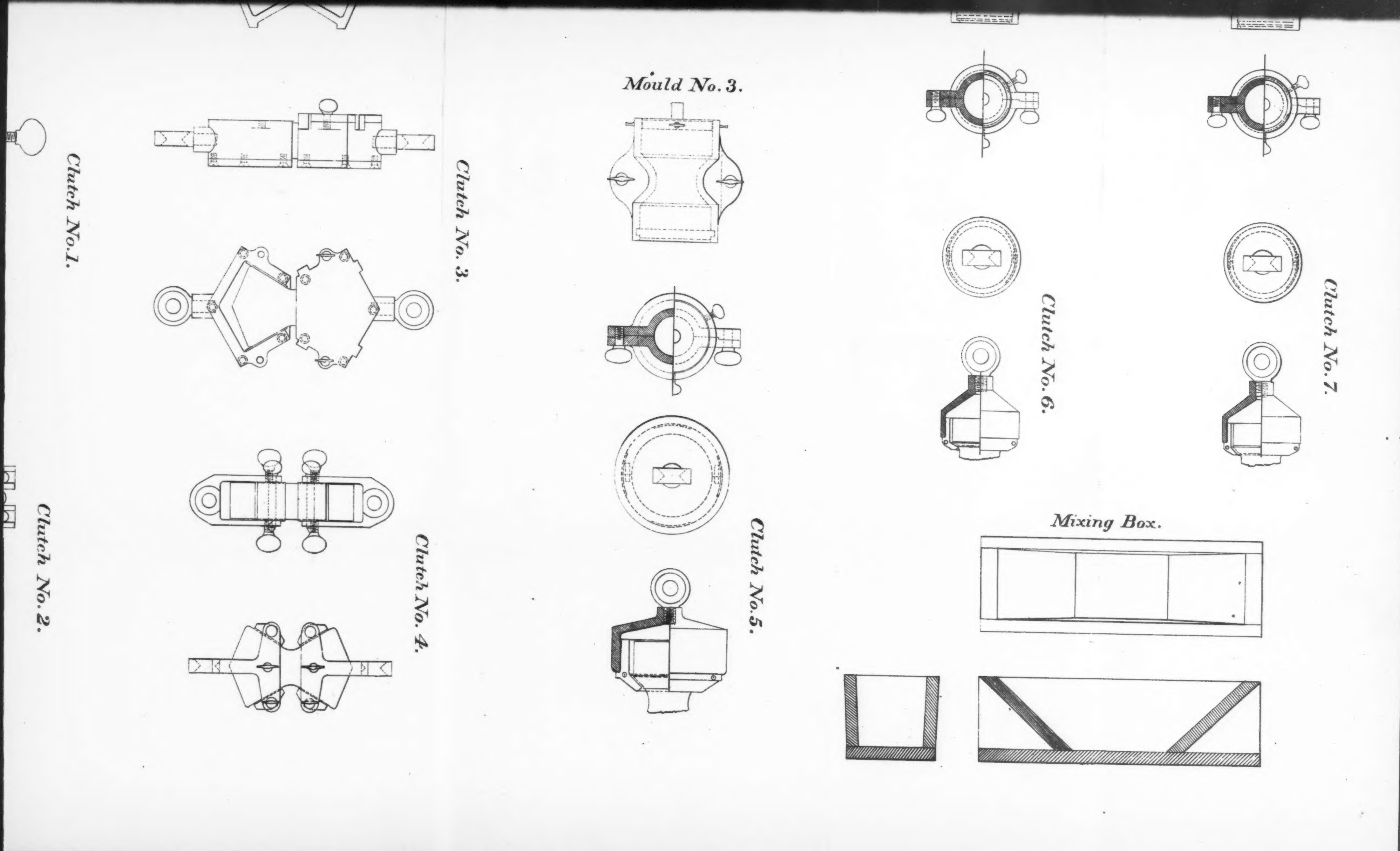


Clutch No.1.



Clutch No. 2.




Clutch No. 1.
Clutch No. 2.
Clutch No. 3.
Clutch No. 4.
Mould No. 3.
Clutch No. 5.
Clutch No. 6.
Clutch No. 7.
Mixing Box.

pressure to give the required amount of friction to hold the briquette during the application of the breaking weight without reaching the (considerably higher) degree of pressure which will crush it. Sometimes, during the application of the weight, the clutch would slip, thus throwing the strain aside from the axis of the briquette and giving a lower breaking weight the best results were obtained when the pressure was barely sufficient to hold the specimen without permitting the clutch to slip off. Sometimes, when the set screws were not set up sufficiently to hold the briquette, the clutch would slip off, and, on being replaced, the briquette would break with the application of a smaller weight than the one which it had before sustained ; and sometimes the breaking weight would be low without obvious cause. Mortars made from the same barrel of cement, mixed the same hour, would give breaking weights varying as much as 40 per cent. I believed these discrepancies were due mainly to the clutch, for the mortars were mixed and the briquettes moulded very carefully. After the close of work last year I began some experiments to select a better form of mould and clutch.

The several forms experimented with are indicated on the plate as moulds Nos. 2, 3, 4 and 5, and clutches Nos. 3, 4, 5, 6 and 7. In breaking, slips or rings of sheet rubber were placed between the bearing surfaces of the clutches and briquettes.

The moulds Nos. 3, 4 and 5, and the corresponding clutches, are essentially the same in form as those of Mr. Whittemore ; in each form of briquette (No. 2 not included) the shoulder is a frustrum of a cone ; in No. 3 an element of this frustrum makes an angle of 45° with the axis; in No. 4 this angle is 60°; contrary to expectation, briquettes moulded in No. 4 gave considerably less resistance than those moulded in No. 3 ; after a few experiments moulds of form No. 4 were turned out so as to make the angle of the shoulder with the axis 45°. Not enough experiments were made to determine whether this change was a material improvement or not.

The breaking section in each form was 2¼ square inches.

In all the experiments the mortar was made without sand. The cement and water for each briquette were weighed and the mould filled in the manner already described. The briquettes were left in the air 24 hours and then kept in the water 6 days ; they were broken immediately after being taken from the water. The tests recorded in tables I. to VI.

were made in a room where the temperature varied from 32° to 80°; those in tables VII. and VIII. were made in a room where the temperature was maintained between 60° and 70°. The water with which the mortars were mixed was of the temperature of melting ice.

TABLE I.

Comparison of Moulds 2 and 3.

When Made.	Composition: Cement.	Composition: Water.	Mould No. 2: Clutch.	Mould No. 2: Breaking weight, lbs.	Mould No. 2: Mean breaking weight, lbs.	Mould No. 2: Variat. of breaking weight from mean, per cent.	Mould No. 3: Clutch.	Mould No. 3: Breaking weight, lbs.	Mould No. 3: Mean breaking weight, lbs.	Mould No. 3: Variat. of breaking weight from mean, per cent.	
1878.											
Dec. 2	38½	8	No. 3	950 1100 1050	1033	8	No. 5	963 1012 988	988	3	
" 4	35	7	No. 3	969 981 956	969	1	No. 5	950 1100	1025	7	Imperfect.
" 7	35	7	No. 3	894 1069 937	967	10	No. 5	975 1144 1062	1060	8	O. F. Alsen & Co.'s Portland Cement.
" 10	35	7	No. 3	987 938 1019	981	4	No. 5	925 944 1112	994	12	
" 12	35	7	No. 3	925 969 969	954	3	No. 5	1125 1094	1109	1	
1879.											
Jan. 28	35	6¾	No. 3	881 881 888	883	1	No. 5	925 1200 913	1013	18	
" 29	35	6¾	No. 3	862 875 830	858	2	No. 5	1000 1025 1187	1071	10	
Feb. 13	35	7	No. 4	.... 919 931	925	1	No. 5	919 931 1031	960	7	Knight, Bevan and Sturges' Portland Cement.
" 14	35	7	No. 4	863 856 825	848	3	No. 5	1037 1013 937	996	6	
Mean...	......	......	......	....	936	$3\frac{7}{15}$	......	....	1020	8	
Extreme	......	......	......	....	......	10	......	....	......	18	

TABLE II.

COMPARISON OF MOULDS 3 AND 4.

When Made	Composition		Mould No. 3.				Mould No. 4.				
	Cement,	Water.	Clutch.	Breaking weight, lbs,	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	
1879.											O. F. Alsen & Co.'s Portland Cement.
Jan. 28	35	6¾	No. 5	925 1200 913	1013	18	No. 6	800 825 875	833	5	
" 29	35	6¼	No. 5	1000 1025 1187	1071	10	No. 6	863 944 1006	938	8	
Mean...	......	......	......	....	1042	14	......	....	885	6½	
Extreme	......	......	......	....	......	18	......	....	......	8	

TABLE III.

COMPARISON OF MOULDS 3 AND 5.

When Made.	Composition		Mould No. 3.				Mould No. 5.				
	Cement.	Water.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Vari tion of breaking weight from mean, per cent.	
1879.											Knight, Bevan & Sturges' Portland Cement.
Feb. 13	35	7	No. 5	919 931 1031	960	7	No. 7	838 762 950	850	12	
" 14	35	7	No. 5	1037 1013 937	996	6	No. 7	862 869 813	848	4	
Mean...	......	......	......	....	978	6½	......	....	849	8	
Extreme	......	......	......	....	......	7	......	....	......	12	

The experiments show that Mould No. 3 developed greater tensile strength, and Mould No. 2 gave more uniform results, than the other patterns.

The next experiments were made to determine whether the application of pressure while the mortar is setting, results in improvement in strength and uniformity. The plate shows a follower in the upper end of moulds 3, 4 and 5. A weight was applied to this, equivalent to 32 lbs. per square inch of section of the head of the briquette ; after the application of this weight for two minutes, the follower was secured in place by the set screws, and the weight removed. An experiment appeared to show that the full effect of the pressure, as regards the strength of the briquette, was obtained in this way.

The briquettes made in Mould No. 2 were formed as described on pages 3 and 4, without the final application of pressure while setting.

TABLE IV.

Comparative strength of briquettes made in Mould No. 2 in the ordinary manner, and briquettes made in Mould No. 3, setting under a pressure of 32 lbs. per square inch.

When Made.	Composition		Mould No. 2.				Mould No. 3.				
	Cement.	Water.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	
1878.											
Dec. 23	35	7	No. 3	1150 937 1119	1069	12	No. 5	1625 1331 1500	1485	10	O. F. Alsen & Co.'s Portland Cement.
" 24	35	7	No. 3	1000 975 956	977	2	No. 5	1275 1675 1206	1370	20	
" 26	35	7	No. 3	1062 1075 1013	1050	4	No. 5	1655 1469 1469	1531	8	
" 27	35	8	No. 3	950 950 850	917	7	No. 5	1325 1350	1338	1	
" 28	35	8	No. 3	994 912 888	931	7	No. 5	1188 1325 1337	1283	7	
1879.											
Jan. 25	35	6¾	No. 3	938 956 1012	969	4	No. 5	1487 1488 1450	1475	2	
" 27	35	6¾	No. 3	994 969 1087	1017	7	No. 5	1650 1638 1687	1658	2	
" 30	35	7½	No. 3	1081 975 1100	1052	7	No. 5	1375 1412 1125	1304	14	
Feb. 1	35	7½	No. 3	1000 1050 1138	1063	7	No. 5	1350 1281 1375	1335	4	
" 11	35	7	No. 4	875 869 825	856	4	No. 5	1287 1288 1269	1281	1	Knight, Bevan and Sturgis' Portland Cement.
" 12	35	7	No. 4	869 906 850	875	4	No. 5	1281 1106 1363	1250	12	
Mean...	......	......	......	....	980	$5\frac{10}{11}$	......	....	1396	$7\frac{4}{11}$	
Extreme	......	......	......	....	......	12	......	....	......	20	

From table No. I. we find the ratio of strength of briquettes Nos. 2 and 3=

$$936:1020=1:1.09 \qquad (1)$$

all setting without pressure.

From table IV. we have the ratio

$$980:1396=1:1.42 \qquad (2)$$

Combining ratios (1) and (2) we have

$$\frac{1.42}{1.09}=1.30$$

Showing that the application of the pressure to the mortar while setting increased its strength about 30 per cent. There is no improvement, however, in uniformity.

TABLE V

Comparative strength of briquettes made in Mould No. 3 with those made in Mould No. 4, all having set under a pressure of 32 lbs. per square inch.

When Made.	Composition		Mould No. 3.				Mould No. 4.				
	Cement.	Water.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	
1879. Jan. 25	35	$6\frac{3}{4}$	No. 5	1487 1488 1450	147[illegible]	2	No. 6	1288 1437 1325	1350	6	O. F. Alsen & Co.'s Portland Cement.
" 27	35	$6\frac{3}{4}$	No. 5	1650 1638 1687	1658	2	No. 6	1462 1388 1494	1448	5	
" 30	35	$7\frac{1}{2}$	No. 5	1375 1412 1125	1304	14	No. 6	1100 1231	1166	6	
Feb. 1	35	$7\frac{1}{2}$	No. 5	1350 1281 1375	1335	4	No. 6	1313 1306 1250	1290	3	
Mean...	......	......	......	....	1443	$5\frac{1}{2}$	......	....	1327	5	
Extreme	......	......	......	....	......	14	.....	....	......	6	

TABLE VI.

Comparative strength of briquettes made in Mould No. 3 with those made in Mould No. 5, all having set under a pressure of 32 lbs. per square inch.

When Made.	Composition		Mould No. 3.				Mould No. 5.				
	Cement.	Water.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	
1879. Feb. 11	35	7	No. 5	1287 1288 1269	1281	1	No. 7	1250 1319 1312	1294	3	Knight, Bevan & Sturges' Portland Cement.
" 12	35	7	No. 5	1281 1106 1363	1250	12	No. 7	1431 1288 1250	1323	8	
Mean...	......	......	......	....	1266	6½	......	....	1309	5½	
Extreme	......	......	......	....	......	12	......	....	......	8	

The breaks in briquettes of patterns 2, 3 and 4 were central; the breaks in briquettes of pattern 5 were at the shoulder.

After the conclusion of these experiments the moulds No. 2 and clutches No. 4 were sent to Saul Ste. Marie for comparison with mould No. 1 and corresponding clutches.

TABLE VII.

Comparison of Strength of Briquettes of Patterns 1 and 2.

When Made.	Composition		Mould No. 1.				Mould No. 2.				
	Cement.	Water.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	
1879. Mch. 8	32	7	No. 2	1038 1159 1322	1173	13	No. 4	940 875 956	927	6	Knight, Bevan & Sturges, Portland Cement.
" 9	32	7	No. 2	1046 1249 1123	1139	10	No. 4	1008 987 979	991	2	
" 10	32	7	No. 1	1157 1164 1195	1172	2	No. 4	794 872 811	826	6	
" 11	32	7	No. 1	1268 1397 1462	1376	8	No. 4	903 1018 995	972	7	
" 11	32	7	No. 1	1414 1246 1191	1284	10	No. 4	984 983 970	979	1	
" 15	32	7	No. 1	1288 1252 1300	1282	2	No. 4	832 816 840	829	2	
" 17	32	7	No. 1	1251 1254 1145	1217	6	No. 4	913 763 859	845	10	
" 18	32	6	No. 1	1502 1518 1673	1564	7	No. 4	945 984 966	965	2	
" 19	32	7	No. 1	1411 1218 1322	1317	8	No. 4	948 944 904	932	3	
" 19	32	7	No. 1	1370 1317 1384	1357	3	No. 4	843 887 887	872	3	
" 20	32	7	No. 1	1339 1326 1389	1351	3	No. 4	790 766 893	816	9	
" 21	32	7	No. 1	1283 1206 1254	1248	3	No. 4	816 855 761	811	6	
Apl. 21	35	7	No. 1	1531 1227 1363	1374	11	No. 4	847 893 856	865	3	
" 23	35	7	No. 1	1203 1329 1155	1229	8	No. 4	857 927 898	894	4	

TABLE VII.—*Continued.*

Comparison of Strength of Briquettes of Patterns 1 and 2.

When Made.	Composition		Mould No. 1.				Mould No. 2.				
	Cement.	Water.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	
1879.											Knight, Bevan & Sturges' Portland Cement.
" 26	35	7	No. 1	961 1107 1114	1061	9	No. 4	756 816 772	781	4	
" 28	35	7	No. 1	1101 1118 1169	1129	4	No. 4	796 884 892	857	7	
" 29	35	7	No. 1	1347 1275 1234	1285	5	No. 4	903 934 957	931	3	
" 29	35	7	No. 1	1279 1317 1288	1295	2	No. 4	856 835 860	850	2	
Mean...	......	......	......	....	1270	$6\frac{1}{3}$	......	....	886	$4\frac{3}{5}$	....
Extreme	......	......	......	....	......	13	.....	....	......	10	....

$$\frac{1270}{886} = 1.43.$$

Table VII. shows that briquettes of pattern 2, broken with clutch No. 4, did not develop the full strength of the cement; in order to learn whether this was due to the clutch or to the form of the briquette, the tests recorded in the following table were made. All the briquettes were made in moulds No. 2.

TABLE VIII.

When Made.	Composition		Mould No. 2.				Mould No. 2.				
	Cement.	Water.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	Clutch.	Breaking weight, lbs.	Mean breaking weight, lbs.	Variation of breaking weight from mean, per cent.	
1879.											
May 5	35	7	No. 1	885 1104 969	986	12	No. 4	779 778 788	782	1	Knight, Bevan & Sturges' Portland Cement.
" 5	35	7	No. 1	858 833 986	899	10	No. 4	890 825 829	848	5	
" 6	35	7	No. 1	1088 932 1010	1010	8	No. 4	918 914 948	927	2	
" 6	35	7	No. 1	1031 893 944	956	8	No. 4	912 893 840	882	5	
" 7	35	7	No. 1	1086 1070 1059	1072	1	No. 4	955 897 1003	952	6	
" 8	35	7	No. 1	1249 1190 1128	1189	5	No. 4	909 1112 1008	1010	10	
" 9	35	7	No. 1	1131 932 961	1008	12	No. 4	994 982 1062	1013	5	
" 10	35	7	No. 1	1125 1036 1262	1141	11	No. 4	1035 992 899	975	8	
Mean...	......	......	......	......	1033	$8\frac{3}{8}$	......	....	924	$5\frac{1}{4}$	....
Extreme	......	......	......	....	......	12	......	....	......	10	....

$$\frac{1033}{924} = 1.12.$$

Comparing the ratios deduced from tables VII and VIII, it appears that mould No. 1 gives results about 30 per cent. higher than those obtained from No. 2.

In his recent work on Portland cement Mr. Henry Reed refers with some asperity to those who have used forms of moulds differing from the one originally recommended by him to the Metropolitan Board of

Works; but it appears from his pages that he also has indulged in the reprehensible practice of innovating.

At this time, when no particular form of mould is in general use, no valid objection can be made to such experiments and variations as may lead finally to the selection of a form which will give, with the same cement, uniform results, and, at the same time develop its full strength; then, uniform conditions being observed, the results obtained by one experimenter may be of value to another for comparison.

None of the forms of moulds and clutches which I have used fill both of these requirements. The apparatus giving the most uniform results develops the least strength.

These experiments are submitted to the Society, because they show that with a proper apparatus much higher results may be obtained from a given quality of cement than those heretofore reported; that the form of apparatus affects these results in a much higher degree than is generally supposed, and because I believed that although not successful in attaining the object sought, a report of my failures would not be without interest to those who have become interested in testing cement.

Discussion by D. J. Whittemore.

Mr. Noble shows the necessity of having a standard form of mould and clutch for tensile tests of cement. Mr. Maclay has shown the necessity of uniformity of exposure of the samples, effect of temperature, etc. Mr. Noble and others have shown the effect of pressure in moulding; all indicating that to accumulate data comparable, each experimenter should observe similar conditions of manipulation, exposure, and testing, having similar forms of samples, and other like conditions unnecessary at present to mention.

In the matter of tensile strength of cement, it has been, and is still my belief that that form of briquette and clutch which would most nearly indicate the actual tensile strength, should give the most uniform results. The want of uniformity in testing with the ordinary form led me, some years ago, to devise a form essentially the same as No. 3 used by Mr. Noble, and the resulting tests from it were generally high, but had a sad want of uniformity until I discarded the use of rubber rings between the bearing surfaces of the briquette and cup-clutch, after which

the percentage of discrepancies was reduced to about the same in the use of my modified form of the common briquette.

My observations lead me to believe that the injurious effect of rubber so used, lies in the fact that its extreme adhesive power does not permit the cup-clasps to take their exact proper position under strain. It is very difficult, if not impracticable, to set the two clutches and briquette by the unaided eye, so that the line of strain shall be axial throughout, and if this is not done excessive strains will be generated in an extreme part of the section of briquette, resulting in discordant determinations. Without rubber intervening, my experience is that the parts adjust themselves to the line of strain more easily and perfectly. I trust that Mr. Noble will give form No. 3 a further trial without the use of rubber-bearing surfaces. It would, perhaps, be unfair for me to imply or assert that from the causes mentioned arises the excessive percentage of variation shown by Mr. Noble in the use of Form No. 3. I only state my experience with it, and know not what expedient he adopted to overcome the difficulty mentioned.

I am of the opinion that a decidedly better form of cylindrical briquette can be made, one that will in a great degree overcome this difficulty, and the form I have devised for this purpose is shown in the accompanying sketch, Plate No. III., which shows also the cup-clutch in section. This form of briquette has at each end a spherical enlargement fitting cup-clutches, at the bearing surfaces, like the ball and socket joint—not cone-shaped, as in form No. 3. By lubricating the bearing surfaces of the clutch the briquette will adjust itself easily, when under strain, to its proper position. The circular briquette permits moulding and setting of cement under definite pressure without changing the breaking section, a quality not possessed by the usual form.

The accompanying sketch is full size for briquettes having a breaking area of one square inch, which, though less than the usual size, is, in my opinion, large enough for the purposes desired. The amount of cement required by this size is consequently but a fraction of that generally used, which is a great desideratum with those experimenters who are required to prepare the cement from the native rock by crucible burning, and grinding with mortar and pestle. It is my intention to experiment with this form the coming winter, and report to this Society the evidence deduced.

Except for critical work I have extensively used my modified form of

Briquette & Cup Clutch

designed by
D. J. Whittemore

Explanation:

A & B forms the Cup-Clutch and should be made of Gun Metal or Soft Steel.

C, Briquette

D. Brass Ring for holding the two halves of Cup Clutch B in place.

TRANS. A
VOL
WHIT
APPLIANCES

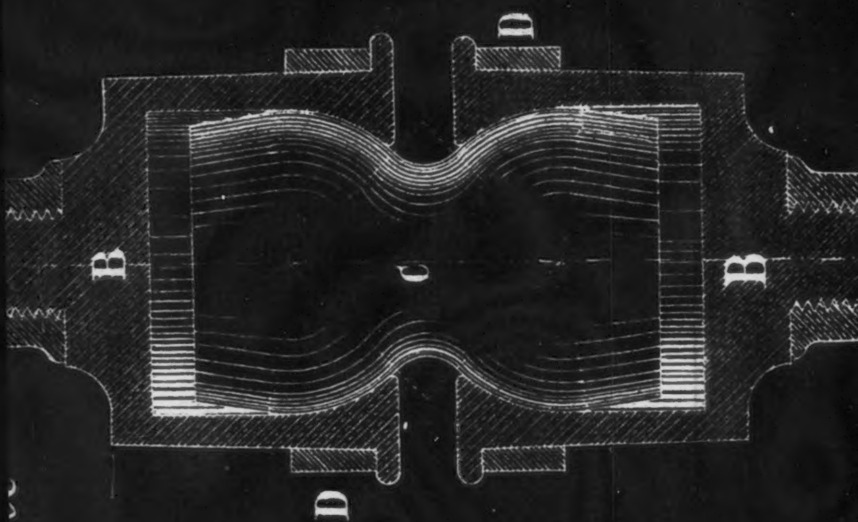


PLATE III
ANS. AM. SOC. CIV. ENG'R'S
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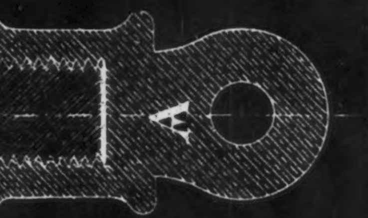
WHITTEMORE ON
ANCES FOR TESTING CEMENT



Combined Clutch and Mold

designed and used by
D. J. Whittemore
for his modified form of Common Briquette

Front

Full Size

Side

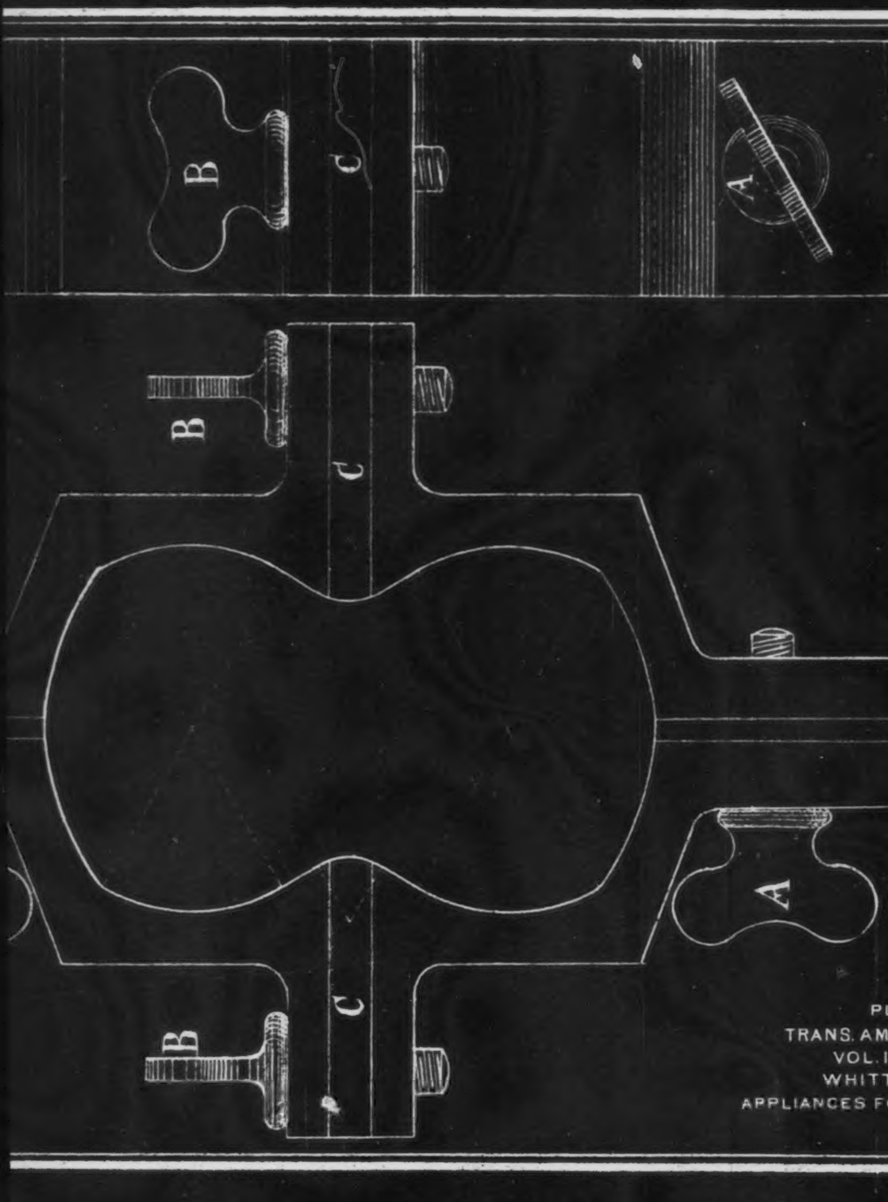


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PLATE IV
S. AM. SOC. CIV. ENG'R'S.
VOL. IX Nº CXCII
HITTEMORE ON
ES FOR TESTING CEMENT

the common briquette shown in the sketch, Plate No. IV. In this form the mould is transformed into the clutch by simply removing the screw bolts B, B, and the fillers, C, C, In moulding, these parts are in place, and the moulded sample is not removed by pressure but by loosening the screw bolts A, A, allowing the mould to be separated longitudinally, and the moulded briquette to pass out easily. In testing, care is taken to introduce the test sample between the corresponding parts of clutch in which it was moulded, thus insuring a perfect fit.

It may not be out of place for me to express the opinion that undue value is placed on experiments, as heretofore conducted, in ascertaining the tensile strength of cements to the exclusion of nearly all other tests. In my opinion, one of the most satisfactory tests of the value of this material, is that so largely employed by Gen. Gillmore in accumulating data for his work on "Limes and Hydraulic Cements," to wit: that of subjecting specimens moulded in the form of parallel opipedons, to transverse stress.

I again suggest that it is eminently proper for this Society to recommend a code of rules for testing cements. I feel that not one of its members would fail in an endeavor to comply with such reasonable rules as would probably be suggested, and that in the course of a short time, by a close observance of such rules, and availing ourselves of the experience already gained, both at home and abroad, we shall accumulate comparable data from which to more understandingly judge of the strength and value of this wonderful production.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

CXCIII.

(Vol. IX.—May, 1880.)*

DESIGN AND CONSTRUCTION TABLE FOR EGG-SHAPED SEWERS.

BY C. G. FORCE, JR., C. E., Member of the Society.

READ AT THE ELEVENTH ANNUAL CONVENTION, JUNE 17, 1879.

The design for the cross-section of the first brick-sewers constructed in Cleveland (except for steep grades) was substantially the usual egg-shaped section common in England and in this country. The arch is a semicircle, consequently the greatest breadth of the section is at the spring-line. The vertical diameter is one and one-half times the transverse diameter; hence the spring-line of the arch is two-thirds of the vertical diameter above the base of the section. The *radii* of the side arcs are equal to the vertical diameter, and the radius of the lower arc is one-fourth of the transverse diameter of the section. The curvature of the side arcs is, therefore, slight.

In the construction of brick-sewers in Cleveland, in accordance with this design, great difficulty was experienced in holding the invert and side walls in proper shape until the arch could be completed and loaded, and failures had occurred in completed work by buckling in of the side

walls immediately below the spring line of the arch from the lateral pressure of the quicksand and water which underlie the city, and are constantly met with at the depth the sewers are built. These failures occurred in sewers of the dimensions of 6x4 feet, with 8-inch walls of brick, laid in hydraulic cement, and without headers, except one course at the spring-line of the arch, in cuttings, from 12 to 15 feet in depth. The brick invert was laid in a plank invert held in shape by curved ribs cut from plank and planed inside.

Taking these facts, and estimates made at the time, as a basis, it was deemed impracticable to construct brick sewers larger than 4½x3 feet with this form of section through material of the character met with in Cleveland without a specially prepared foundation, or a thickness of walls disproportionate to the size of the sewer when in comparatively dry cuttings, and consequent disproportionate increase of cost.

The difficulties in construction, referred to above, were obviated, and the stability of the completed work insured, without materially decreasing the carrying qualities of the sewers, subject to an intermittent flow, by the adoption of the form of section shown on Plate V., Fig. I.* The construction is as follows: Describe the circle *C B D* and make the arcs *B E* and *D E* each equal to one-sixth of the circumference, and the arcs *B C* and *D C* each equal to two-sixths of the circumference. Through the points *B* and *C*, *D* and *C*, *B* and *E*, *D* and *E*, draw the indefinite straight lines *B F*, *D G*, *D H*, and *B K*, respectively, and with the point *C* as centre, and a radius equal to the radius of the circle, describe the arc *F G*, and with the points *B*, *D* and *E* as centres, and the *radii B F*, *D G*, and *E H*, describe the arcs *F K*, *G H*, and *H K*, respectively.

It will be observed that in this cross-section the spring-line of the arch is nearly identical with a horizontal line passing through the middle point of the vertical diameter; therefore, in the construction of sewers with this form as compared with the usual egg-shaped section in which the spring-line is two-thirds of the height above the base, the amount of brickwork laid upon the centering is proportionately larger, and the more expensive, and usually most neglected portion of the work, is proportionately less, and at the same time the *height* of the side walls to be held in position until the arch can be loaded, referred to above, is very

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* Designed by the writer.

materially decreased, a matter of considerable moment in the construction of large sewers through bad ground.

As to the necessary thickness of walls for this design, the practice is to have for sewers not larger than 6 x 4½ feet, 8-inch walls, in cuttings from 14 to 18 feet in depth, and 12-inch walls, for sewers from 6 x 4½ feet to 7¾ x 6 feet, in cuttings from 16 to 22 feet in depth, using a plank invert only for a foundation, thus showing the expediency of the adoption of a form of cross-section more nearly approaching a circle, as compared with the usual egg-shaped section for sewers with ordinarily imposed conditions, in localities where the material through which they are to be constructed is, or is liable to be, surcharged with water.

Fig. II, Plate V., shows the same design as Fig. I, and will assist in the analysis of the calculations and the application of the following:

Let R = Radius of lower arc of 60°.
" A = Area of section.
" C = Circumference.
$\pi = 3.1416$.

$$\text{Then } A = R^2 \left[\pi\,(3.1666.. + \sqrt{3}) - \sqrt{3} \right]$$

$$C = \frac{\pi R}{3}(4 + 5\sqrt{3})$$

$$\text{Vertical diameter} = R\,(3 + \sqrt{3})$$

$$\text{Transverse " } = R\,(2 + \sqrt{3})$$

Taking $R = 1$ in the above formulæ.

$$\text{Then } A = \pi\,(3.1666.. + \sqrt{3}) - \sqrt{3} = 13.6577.$$

$$C = \frac{\pi}{3}(4 + 5\sqrt{3}) = 13.2581.$$

$$\text{Vertical diameter} = 3 + \sqrt{3} = 4.7321.$$

$$\text{Transverse " } = 2 + \sqrt{3} = 3.7321.$$

And the area of *any* section $= 13.6577..\ R^2$.

The following table shows a series of sizes for brick sewers, No. 1* to No. 16 inclusive, adopted by the City of Cleveland, and is here given as an illustration of a convenient method of notation in connection with a series of areas which in practice fulfills the requirements of ordinary city and town sewerage, taking a "foot" as the unit of area.

The areas A, in the second column, are derived from assumed con-

* Not used.

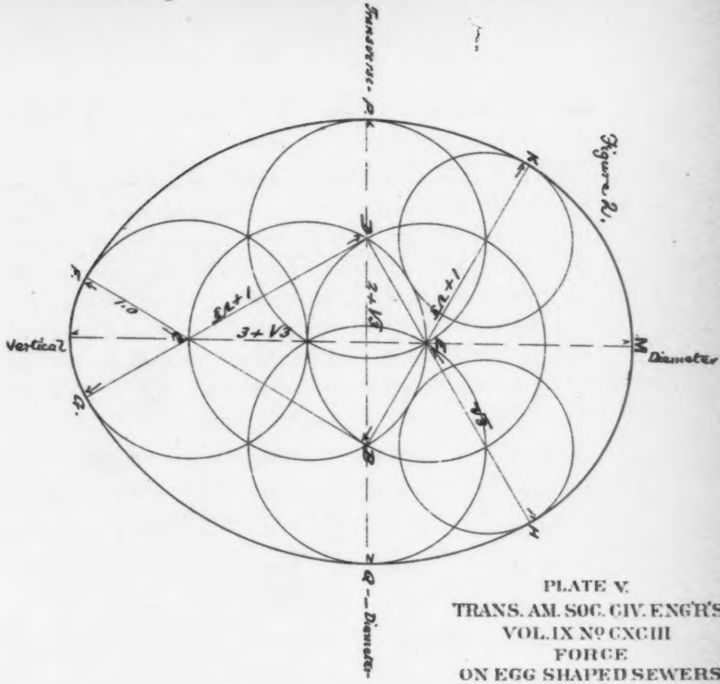

PLATE V.
TRANS. AM. SOC. CIV. ENG'R'S
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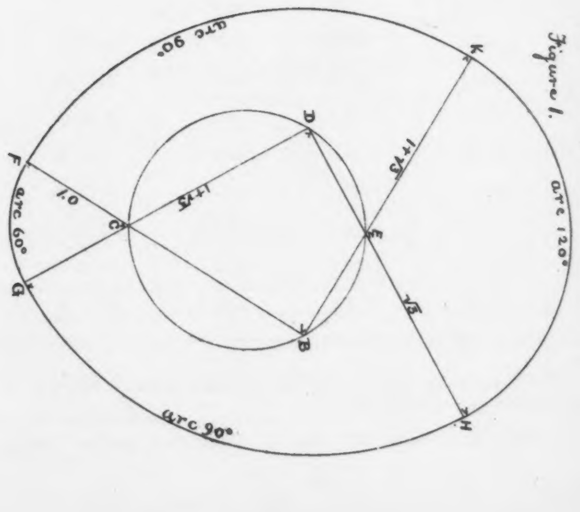
FORCE
ON EGG SHAPED SEWERS.



secutive numbers N, in first column, and are equal to $\sqrt[3]{N^4}$, N denoting size as, size No. 1, &c.

The vertical and transverse diameters are given in units corresponding to the unit of area.

Assumed consecutive number denoting size. $= N$.	Sectional Area. $= \sqrt[3]{N^4} = A$.	Radius of lower Arc of 60° $= R$.	Vertical Diameter.	Transverse Diameter.
1........	1.0000	0.2706	1.2805	1.0098
2........	2.5198	0.4295	2.0326	1.6031
3........	4.3268	0.5629	2.6634	2.1006
4	6.3496	0.6818	3.2265	2.5447
5........	8.5499	0.7912	3.7441	2.9528
6........	10.9027	0.8935	4.2279	3.3345
7........	13.3905	0.9902	4.6855	3.6953
8........	16.0000	1.0824	5.1218	4.0394
9........	18.7208	1.1708	5.5402	4.3694
10........	21.5443	1.2560	5.9433	4,6873
11........	24.4638	1.3384	6.3332	4.9948
12	27.4731	1.4183	6.7114	5.2931
13........	30.5674	1.4960	7.0793	5.5833
14........	33.7420	1.5718	7.4378	5.8660
15........	36.9932	1.6458	7.7879	6.1421
16........	40.3175	1.7181	8.1303	6.4122

The areas A in the second column are based upon assumed consecutive numbers N, denoting size, in the first column, and are $A = \sqrt[3]{N^4}$

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NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CXCIV.

(Vol. IX.—May, 1880.)

THE PRESERVATION OF TIMBER.

By J. W. PUTNAM, Associate A. S. C. E.

READ OCTOBER 15TH, 1879.

In January, 1869, work was commenced on the construction of a line of railroad between New Orleans and Mobile. The road extends for nearly fifty miles through a flat, marshy country, crossing various streams and bayous, which are at certain seasons of the year tidal and infested by the *Teredo Navalis*. From thence to Mobile it passes

through a higher sandy country, crossing several tributaries to and arms of the Gulf, also salt, in which the ravages of the *teredo* are very great. The bridges over all the water-ways were constructed on pile foundations. Yellow pine was generally though not always used for piles, and driven soon after being cut. During the months of May and June, 1869, a part of the piles were driven for the bridge across Bay St. Louis, a sheet of salt water two miles wide, and the work was then suspended until the following fall and winter, when the bridge was completed. During the succeeding November, or in less than nine months from the completion of the bridge, the piles began to give way and break off, being thoroughly honeycombed. A few weeks later the piles began to break in the bridge over Bay Biloxi—a bridge one and one-fourth miles long—and during the month of April following it broke down, letting an engine and four freight cars into the bay. The work of rebuilding was begun during the winter of 1870 and 1871, or within two years of the time of turning the first shovelful of earth in the construction of the road. The Bay St. Louis bridge was built on piles sheathed with yellow metal, and the Biloxi bridge on piles sheathed with zinc. The piles were hewn to one foot diameter, covered with a layer of felt, and then with the metal, the whole being securely nailed. The other bridges were not entirely rebuilt at that time, but had new piles driven underneath, and sprung into position. In the Pascagoula and Pearl rivers—streams from twenty to fifty feet deep, and having very strong currents during the spring floods—piles were perforated by the teredo from within five or six feet of the surface of the water to the bottom, and some of them were found to be cut completely off. The sheathing was found to be an efficient protection for the piles as long as it remained intact, but the waters of these harbors were found to contain something which, uniting with both kinds of metal, dissolved and rendered them worthless in a few years. The yellow metal lasted about twice as long as the zinc.

With the great number of bridges subject to the attacks of the *Teredo Navalis* the contest was now seen to be one of life or death.

The *Teredo Navalis* is an inhabitant of salt or brackish waters and lives within timber, the most of which has been carried out to sea by rivers. Hence, it is not probable that it would inhabit the waters of a rainless coast.

It is of a translucent and jelly-like consistence, varying in size from

a creature invisible to the naked eye to one, two, or more feet in length, with a diameter of five-eighths of an inch. I have been informed that specimens one inch in diameter and four feet long have been taken from the planking of ships.

It seems to grow about two inches in length a month, and appears to live from eight to sixteen months. Between March and May the greater part of the old ones disappear. The young make their appearance in March, but do not become abundant until May, and continue to develop until November. It is a solitary animal, living in a cell alone, and having no communication with its fellows. It is probably hermaphrodite, and like other low forms of life, is very prolific, a single one depositing from one to three million eggs in a season. The eggs, I think, are only hatched by the action of salt water, as no young appear when the water is fresh by reason of rain. The eggs have been supposed to hatch within a week of their deposition in water, but I think they often remain much longer, and perhaps some of them pass the entire winter afloat. Having been hatched, they swim about in search of food, and in this condition millions of them must be carried out to sea by ebbing tides and distributed to other ports, or perish by starvation.

If they come in contact with timber which suits their taste, they attach themselves by a foot or sucker and enter, making their way by means of a pair of forceps-like cutters. The cutters are a pair of concave or partly spherical shells placed on each side of the head, and extending partly over it. They are joined by a hinge-like joint at one end and free at the other, and are moved by a firm, strong muscle, which is attached to the lower edge. In the center of the head and between the free edges of the cutters is a firm muscular foot or sucker, by which the animal holds itself in position for work. Beneath the free ends of the cutters is the mouth or orifice leading to the stomach, to which further reference will be made.

The hole cut for entrance is very minute, so small as to be seen only by the closest observation. Having entered the timber and begun to feed, they enlarge rapidly. The cavity cut is lined with a shelly deposit of carbonate of lime, to which the animal is attached near the point of entrance by a muscular coat and the skin, shutting out all water except that taken through canals in the body for respiration and lime. At the tail are two oar-shaped bones or shells, the blades of which are ribbed like a file, the long, round ends extending inside the body. By means

of the muscular coat attached to the lining shell it is enabled to project these file-like bones outside the timber, thus removing obstructions, maintaining communication with the water, and enlarging the orifice to meet the increasing demands of the growing animal. It may also serve as a protection against the depredations of other animals by closing the orifice and presenting a front of solid lime. In fact, I do not see how any animal can attack it without first being able to tear down its armament. Should an entrance be attempted while the bones are drawn in, at the first alarm they would be forced out, and being tapering, the intruder would find himself in a vice-like trap from which it would be difficult to escape.

In the operation of feeding, the teredo places its foot or sucker against the wood. The two muscles move the cutters like a pair of forceps or scrapers. The chips are carried to the orifice or mouth before referred to, and thence to the stomach. Open an animal freshly taken from the water, press the stomach, and the contents will flow out through the mouth. Place these under a powerful microscope, and the cuttings are plainly discernible.

The stomach is a brown, oblong sac a little below the head. From its lower end extends a long intestine or alimentary canal. This passes about one-fourth the length of the animal downwards, and turning in a loop, passes back to the head, where it forms another loop beneath the foot or sucker, and then passing downwards the entire length of the animal, discharges at the orifice between the two file-like bones at the tail. This connection may be traced in some of the specimens exhibited to the Society. From this it will be seen that the teredo cuts timber for food, and not as a burrow. I have also noticed that on coming in contact with timber not suitable it retracts one-fourth, more or less, of its length, and abandoning its old cell, cuts a branch in another direction, always taking care to build a large dam or wall across the entrance to the abandoned cell. I have seen three different branches cut by the same animal.

I do not see why the teredo has generally been supposed to cut with a rotary motion. Any one who will take the trouble to sharpen the end of a pipe, and place in the center a soft, elastic point, and revolve the pipe forward and back will see the value of such a cutter.

Beside the canal or duct mentioned there are others, extending from the vital organs to the orifice, which I have not traced out and exam-

ined as thoroughly as desirable. The ovary is a large gland situated between the stomach and first loop in the intestine. It becomes enlarged and active in the winter and early spring in animals which have attained any considerable size. I have reached no satisfactory conclusion on the subject of their reproduction, and will only give a brief *resume* of observations.

Early in March a few animals may be found which have just entered the timber. As the season progresses the number which have just entered increases until the first of October. From that time the number decreases rapidly until the last of November. Through December and January I find none. Having entered the timber they grow in length about two inches a month. In February and March the largest animals are found. I have taken them out measuring twenty-three inches, and large numbers can be found at this season from fifteen to eighteen inches in length, with the ovary so filled with eggs that the smallest part pressed between two glasses in a microscope magnifying three hundred and fifty diameters will show from thirty to a hundred in a single field. I have estimated that a single ovary would contain three million eggs. During April the large animals all disappear, and only the smaller ones up to four or six inches in length remain.

I do not think clear fresh water necessarily destructive to them, as I have seen the water of the bays along the coast fresh enough for good drinking purposes by reason of heavy and continual rains for two or three months, and yet they appeared healthy and vigorous. I have reliable information that vessels have been taken up the Mississippi river to New Orleans—over a hundred miles—during the low stage of the river, when but little sediment was carried, and tied up for the purpose of killing the worms; but when placed in the dry docks two or three months later the worms were found to be in an unprofitably healthy and vigorous condition. If the water be roily, or loaded with silt from heavy rains, it will probably destroy them. During heavy rains, and while the water is fresh, I have not found young animals entering timber, and have supposed that the eggs are only hatched by the action of salt water, as some seeds will only germinate under peculiar conditions.

It has been supposed that the teredo leaves the timber in search of other fields. This probably comes from the sudden disappearance of large numbers in the spring. As they are attached to the shell so firmly as to exclude the entrance of water, they can no more leave it than can

the oyster its shell. Having fulfilled their mission they die, and from their soft, boneless construction they rapidly decompose, and are washed away, leaving only their shell and cutters.

The rapid destruction of timber in exposed situations by decay, and the ravages of land and marine animals, have led people in every age to devise measures to prevent such waste of time and means, and render their works more enduring. The Egyptians—famous for their work in stone —buried their kings in coffins of wood that will endure until those grand old pyramids shall crumble to dust. They saturated their planks with what appears to have been a hydro-carbon or asphaltic oil, and they have stood the test of the few thousand years that have passed since they were prepared.

Modern investigators have ploughed a wide field in search of something which would be equally effective and comparatively inexpensive. Hundreds of patents have been secured, and, with a flourish of trumpets, some have been put to use, only to run a brief race and quietly subside.

Perhaps the only preparation that has stood the test is a hydro-carbon, a product of the destructive distillation of coal. About the year 1835 experiments were begun with this product, usually called creosote or dead oil. It is rich in phenols, but its greatest ingredient is naphthaline. In the scramble for work, and from a mistaken idea that cheapness of construction is economy, as well as by errors of judgment, much defective work has been done. In some cases such work has given partial satisfaction by increased length of service, while in others the additional outlay has been entirely thrown away, bringing disrepute upon all classes of creosoted timber.

Certain rules have been adopted by engineers in the selection and use of timber, which, while valuable in the use of untreated timber, should be set aside in the use of creosoted material. For instance, in ordinary timber-work for exposed situations, compact, solid heart timber is usually specified, and the cutting and framing, more or less, done on the ground.

Such timber, if treated, will prove difficult to saturate. The soft and unripened growth, or sap-wood, more readily absorbs oil, and becomes the more durable. I am satisfied that the more porous and destructible classes of timber now considered nearly worthless, will, when creosoted, become the most valuable. Fir, swamp ash, and old field pine, when treated, will outlast the best white oak, yellow pine, or cedar uncreosoted. In ordinary use the heart of yellow pine will more

than six times outlast the sap-wood. I have at West Pascagoula pieces of yellow pine, the sap-wood of which was partially saturated with creosote oil in October and November, 1872, and which since then have been exposed to contact with the earth, and unfavorable climatic conditions. Such parts as received oil are as perfectly sound as when cut from the stump, while the untreated sap, and a considerable part of the heart, are entirely rotten.

Timber which, untreated, would decay in one season, will remain in closely packed piles or on the ground, in the most unfavorable conditions, perfectly sound for years.

As far as practicable all cutting and framing of timber should be done before treatment, except in open, porous timber, which has been thoroughly saturated. Holes for bolts may be made if they are fitted so as to exclude water. Ordinary building timber will not be thoroughly saturated, and too much care cannot be taken in this respect.

From what I have seen of creosoting, I consider timber which has been saturated with coal-tar oil practically indestructible, and as durable as iron or stone. There is a property in the oil which prevents fermentation and the change which we call decay. How much oil per cubic foot of timber is necessary to produce this result I have not determined. If a small quantity—say five to ten pounds per cubic foot—could be evenly distributed through the stick, it might be sufficient. But as the oil first comes in contact with the outside of the timber the central part will receive none until the outside has become thoroughly saturated. No method is known by which a given quantity of oil less than the total amount which would be absorbed by timber can be so distributed as to reach every part. The amount which can be forced into timber varies from eight to forty pounds per cubic foot. This last amount can only be forced into very light and porous timber.

The unequal results from creosoting timber probably come from the unequal distribution of the oil.

"Of the ties that were treated with creosote oil and laid on the Great Eastern Railroad in England in 1841 eighty per cent. were still doing service in 1862, a period of twenty-one years."

No statement is made as to whether the ties that failed had been thoroughly treated or not. A close examination and report of such con-

ditions would greatly enlighten the public as to the actual value of different kinds of timber and the process of creosoting.

As a defense against the ravages of the *Teredo Navalis*, or ship worm, I think coal-tar oil is invulnerable. It is deadly to cold-blooded animals. A small quantity stirred in a pool where there are fish will kill them. I have placed pieces of treated timber in water where the worms were abundant, and though rapidly entering other timber they would not touch that which had been creosoted.

I have taken pieces of timber, and saturating a part of each one, have left the remainder free from oil. The teredo would enter and destroy the untreated parts, and perish for want of food, leaving the treated parts perfectly good. Wherever it came in contact with the creosoted wood it turned away.

A piece of creosoted plank was inserted in the bottom of a skiff. When the untreated part of the skiff was honeycombed and worthless the treated plank had not been touched.

The bottoms of boats may be protected by drying them and applying what creosote they will absorb.

Water does not unite with the oil, consequently the oil remains in the timber an indefinite length of time.

If this oil be poured in a running stream it will roll along the bottom like molten lead or quicksilver.

A large number of reports on the subject of creosoting, by civil engineers in Europe, have been published during the last fifteen or twenty years, bearing witness to the value of coal-tar oil for the protection of timber against the ravages of land and marine animals. Where the work of creosoting has been properly done piles have stood thirty and forty years, and are still good. Untreated timber, in the same places, would only have stood from two to six years.

From the difficulty of submarine examinations the faithful, thorough creosoting of submerged timber is of more importance, if possible, than where prevention of decay alone is desired.

The trustees for the bondholders of the New Orleans & Mobile Railroad had become so thoroughly convinced of the value of coal-tar oil as a preventive of decay in timber—which takes places rapidly in the long,

warm seasons of that latitude, and of the ravages of the teredo, which is abundant and destructive to the numerous and long bridges which cross the bays and inlets along their line—that they decided in the winter of 1874–5 to creosote the piles and timber used in bridge construction. As no works could be found in this country treating timber thoroughly enough to be satisfactory, it was thought advisable to build machinery and do the work on a plan different from any then in operation. Accordingly, works were erected at West Pascagoula, Miss., at a cost of about fifty thousand dollars, and all the bridges and waterways on the road have been constructed of creosoted timber, except the long spans of trusses, which are of iron.

The work has been eminently satisfactory. Pile piers have been built which bid fair to outlast their iron superstructure.

These works contain two reservoir tanks for storing oil, placed in the ground; two tanks for treating timber, six feet diameter inside by one hundred feet long; a large tubular condenser and pump for supplying it with water, a large vacuum pump, an oil pump, a powerful force pump, a hoisting engine for handling timber, a pair of boilers capable of furnishing the required steam, and a super-heater. These are all connected by the requisite pipes and valves.

Each treating tank contains nearly five thousand feet of one-inch pipe arranged in coils, through which super-heated steam is passed for seasoning timber, and also iron rails upon which cars loaded with timber are moved in and out. Both heads of the treating-tanks are moveable. At suitable distances are transfer-derricks for loading and unloading timber. A large number of piles, ninety and ninety-five feet long, have been handled with them.

In work, piles are cleaned of dirt and bark, butted and sharpened, and timber cut and framed ready to be put in position. It is then loaded on iron cars, built for the purpose, and hauled into the tank.

Steam is then turned in through a perforated pipe extending along the inside at the bottom of the tank.

This is continued until the timber has become heated through. The vapor is then condensed, and a partial vacuum produced. Super-heated steam is passed continually through the coils of pipe to vaporize the sap and moisture contained in the timber, and as fast as vaporized it is con-

densed. A partial vacuum being maintained, the moisture vaporizes at a low temperature, and the seasoning proceeds rapidly.

When the timber has become properly seasoned the tank is filled with oil and a pressure applied by means of the pressure-pump of from one hundred and fifty to two hundred pounds per square inch. This pressure is maintained until the pressure-gauge remains constant, showing that the timber will absorb no more oil.

The oil is then drawn off, the load drawn out, and another load which has meanwhile been prepared drawn in and the process repeated.

The consumption of oil by this process has usually been from twelve to eighteen pounds per cubic foot, or from one and one-fourth gallons to two gallons per cubic foot.

Over three gallons per cubic foot have been injected in some loads.

The main features of our plan of treatment are the extraction of the sap or moisture in the timber to prevent fermentation, and also to provide room for oil. Timber can no more be steamed dry than it could be seasoned by boiling. The timber, being cooler than steam, would condense and absorb it, thus accumulating moisture. Water cannot be drawn out of timber by a vacuum alone. If timber retained its moisture by atmospheric pressure, then by removing such pressure it would flow out. But moisture is retained in timber by capillary attraction, which is left in full force when atmospheric pressure is removed. We steam timber to heat it through as being the simplest method of conveying heat; then condense the steam and pump out the air to produce a partial vacuum.

It is well known that water vaporizes in a vacuum at a low temperature. While under pressure the degree of heat at which it vaporizes rises to correspond with the pressure applied. By maintaining a partial vacuum we are enabled to vaporize the moisture rapidly, and at a temperature which will not injure the timber. When the pressure is removed by condensation, the heat absorbed by the timber during the steaming expands the moisture by vaporizing and drives it out. Superheated steam is passed through the coils of one-inch pipe in the treating-tank to maintain the temperature and assist in vaporizing the moisture, and as fast as vaporized the moisture is drawn away by the condenser.

This process is continued until the timber has become satisfactorily

seasoned, when the tank is filled with oil and a pressure of from one hundred and fifty to two hundred pounds per square inch is applied until the timber will absorb no more oil.

It is now nearly four years since the construction of bridges with creosoted timbers was commenced, aud during that time not a fire has caught in the new work from passing trains, while on bridges constructed of uncreosoted timber watchmen were a continual necessity. In this respect we are happily disappointed.